A Review of CPS 5 Components Architecture for Manufacturing Based on Standards

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***Abstract*— The Cyber-Physical System (CPS) is a concept describing a broad range of complex, multi-disciplinary, physically-aware next generation engineered systems that integrate embedded computing technologies (cyber parts) into the physical world. CPS is a broad area of engineering which supports applications across emergency response, air transportation, critical infrastructure, health care and medicine, intelligent transportation, robotic for service, and special smart manufacturing. In particular, CPS is the core technology enabling the transition from Industry 3.0 to Industry 4.0 and is transforming global advanced manufacturing. This paper provides a review of CPS 5 components architecture for manufacturing as well as of CPS components challenges for manufacturing. It then focuses on the standardization challenges and provides a complete review of international standards. From this study we show that there is need for CPS components to be standardized in order to achieve the success of Industry 4.0. A framework of CPS 5 main components for manufacturing based on standards is proposed.**

Keywords*— *CPS, Industry 4.0, Standardization, Embedded Computing Technologies, CPS Components

I. INTRODUCTION

We are currently experiencing the fourth Industrial Revolution in terms of cyber physical systems. [1, 5, 17]. A Cyber Physical System (CPS) is a physical and engineered system, which can monitor and control the physical environment. Most modern computing devices are ubiquitous embedded systems employed to monitor and control physical processes: cars, airplanes, automotive highway systems, air traffic management, manufacturing plants, etc. [1]. In the past, research on embedded systems tended to focus on the design optimization problems of these computational devices. In recent years, the focus has shifted towards the complex synergy between the computational elements and the physical environment with which they interact. The term Cyber-Physical System was coined to refer to such interactions. In CPS, embedded computation and communication devices, together with sensors and actuators of the physical substratum, are federated in heterogeneous, open, and systems-of-systems. Examples include smart cities, smart grids, medical devices, production lines, automotive controllers, and robotics [2].

The presence and importance of CPS is intended as the orchestration of networked computational resources with multi-physics (mechanical, chemical, electrical) systems in industry. The engineering problems are faced daily managing dynamics, time, and concurrency in heterogeneous (interconnected) systems where the amount and complexity of intelligence (the cyber part) is growing rapidly, and where software implementations are a major portion of system design, validation and ultimately verification. Research and education in this field is of strategic importance for business for years to come. Industry and Government in United States have posed CPS at the center of the engineering research agenda since 2007 when the President's Council of Advisors on Science and Technology (PCAST) highlighted CPS as the "number one" Priority for Federal Investments in Networking and Information Technology. Since 2010, the European research and industrial community has focused on CPS as paradigms for the future of systems. Acatech (German National Academy of Science and Engineering) developed and published in 2011, an Integrated Research Agenda for CPSs. CPSs are essential for the future of the system industry worldwide and collaboration at all levels, from practicing engineers to product architects, from tool makers to technology providers, from service to research. The impacts of CPSs on industrial services can lead to seven affordances [1, 2, 3, 4]:

- Engineer better equipment by leveraging operational performance data,
- Optimization of equipment operations,
- Control and manage equipment remotely,
- Predict and trigger service activities,
- Remote diagnostics and replace field service activities,
- Empower and optimize field service,
- Information and data-driven services.

Nevertheless, CPS, as emerging technology and new industrial paradigm, is still lacking of formal methodology to guide the design and the deployment phases. In order to handle such research gap, we decide to focus on the existing and emerging standards attached to CPS in some ways, in order to first have a clear maps of the concepts.

To this aim, we use an accepted CPS architecture for manufacturing to avoid redundancy in analysis and description. We propose an analysis of the standards landscape for CPS in the Industry 4.0 context with consolidated information from governing bodies such as the International Organization for Standardization (ISO), the International Electrotechnical

Commission (IEC), Guobiao Standards (Standardization Administration of China GB), and Deutsches Institut for Normung (DIN). We propose a framework of CPS 5C architecture based on standards for manufacturing to avoid gaps between CPS components and standardization bodies.

We base our research through professional association (IEEE, google scholar and web of science), extracting literature using the keywords (CPS, Industry4.0, Standardization) for the duration from 2010 – 2017. We so found international standards, European standard and national standards and we selected those standards which had relation with CPS 5C Fig.2.

The paper is organized as follows. Section 2 presents the CPS 5C architecture for manufacturing. Section 3 is dedicated to the challenges related to standardization in the CPS 5C architecture. The proposed framework is detailed in Section 4. Finally, Section 5 deals with the conclusion and future work.

II. CPS 5 Components Architecture For Manufacturing

The 5C architecture proposed by Lee et al. to build the CPS consists of 5 levels, namely the connection, conversion, cyber, cognition, and configuration levels. Fig.1 depicts the 5C architecture. Below we describe the details for each level. [5].

A. Connection

As mentioned in [5], connecting machines and their components for acquiring accurate and reliable data is the first step in developing a CPS for smart factories. Different devices or sensors are used to acquire a variety of data, including the voltage, current, temperature, vibration, rotating speed, feed speed, and oil concentration of machines and their components, as well as images and videos of work pieces. Some sensors are even installed for acquiring temperature, humidity, lightness, atmospheric pressure of the manufacturing field and warehouse. Data may also come from the PLC or manufacturing systems, such as ERP, MES, SCM, and Coordinate Measuring Machinery (CMM). Specific protocols, such as those used in the Internet of Things (IoT) technology, are used to realize data transfer.

B. Conversion

As stated in [5], data are converted into information in this level. Several mechanisms can be used to realize the data to information conversion. Some mechanisms are developed for prognostics and machine health management. This level brings the self-awareness property to the machines.

C. Cyber

The cyber level acts as central information hub in this architecture. Information is being pushed to it from every connected machine to form the machines network. Having massive information gathered, specific analytics have to be used to extract additional information that provide better insight over the status of individual machines among the fleet. These analytics provide machines with self-comparison ability, where the performance of a single machine can be compared with and rated among the fleet. On the other hand, similarities between machine performance and previous assets (historical information) can be measured to predict the future behaviour of the machinery.

D. Cognition

In this level, proper presentation of analytic information is provided to users for making decisions. The priority of tasks for maintenance process can be easily determined due to the availability of comparative information and individual machine status.

E. Configuration

As shown in [5], the configuration level gives feedback from the cyber part back to the physical part. This level performs the supervisory control for making machines self-configured and self-adaptive. It acts as the Resilience Control System (RCS) to apply the controls corresponding to the decisions made in the cognition level to machines.

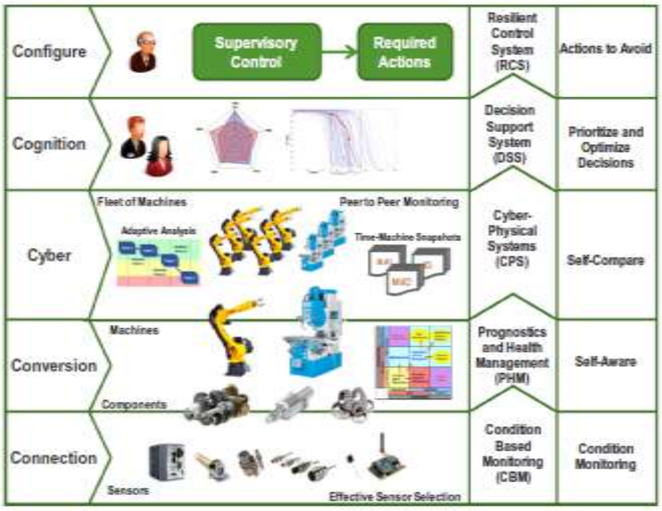


Fig. 1. Applications and techniques associated with each level of the 5C architecture [5]

III. CPS 5 Components Challenge For Manufacturing

A few articles address the challenges of standardization and seamless process integration, seamless data aggregation and disaggregation [7], standardization compliance [8], and product-service innovation, product variety, quality standards, support services, and immediacy or order satisfaction [9]. Industrial Automation Systems (IASs) are commonly developed using the de-facto standard IEC 61131 [8]. Although version 2.0 of IEC 61131 is introduced to address the new challenges of Complex Industrial Automation (CIA) systems, the standard IEC 61499 has been defined to eliminate limitation of IEC 61131. However, we need more and more work on standardization for maturing this new emerging technology [10].

A. Roles and Functions of Standard

Standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose. It appears that different types of standards with different roles and functions are needed for different categories of technology elements to achieve their efficient development and utilization as presented in Table1. It is therefore necessary to define various types of standards according to their basic roles and functions in innovation, in order to discuss mechanics of each generic function along with their complex interactions with technology and other innovation activities.

It is interesting to note that these various types of standards also play an important function of knowledge diffusion between different innovation actors. Transferring new knowledge between and across various stages of technological innovation, standards "help bridge the gap between research and marketable products" (European Commission 2011, p.6). The Expert Panel for the Review of the European Standardization System (EXPRESS 2010, p.16) also notes that "standardization converts new knowledge from scientific research into market" through various types of standards. Table 1 is summarizing examples, knowledge diffusion roles, and economic impacts of various types of standards with different roles and functions [11].

TABLE I. STANDARDS WITH VARIOUS ROLES AND FUNCTIONS [11]

Type	Examples	Knowledge Diffusion	Economic Impacts
Terminology and Semantic Standards	□ Definitions of key concepts and attributes	□ From basic to oriented – basic and applied research	Increased communication efficiency among various stakeholders
Measurement and Characterization Standards	□ Measurement and test methods □ Science and engineering databases, standard reference materials	□ From basic to applied research	Increased research efficacy though more accurate research inputs and verifiable results Higher productivity/ quality through better process control
Quality and Reliability Standards	□ Performance metrics, such as minimum quality levels □ ISO 9000 □ Procedures, such as equipment calibrations	□ From pilot products into mass markets	Expand market share through performance assurance and reduction in transaction costs
Compatibility and Interface Standards	□ Interconnection among system components □ RS- 232 interface standard □ Portability of software across implementation of a computer system	□ From applied research to experimental development □ From computer to printer terminal □ From pilot products into mass markets	Achieve network externalities and thereby expand value / cost rations Facility open systems and thereby enable more competition at component and subsystem levels
Variety Reduction Standards	□ Microprocessor architecture size of silicon wafers □ Bit rate	□ From pilot products into mass markets □ From Tx – Rx Digital Signals	Achieve economies of scale and compatibility across components

B. Standardization Bodies

The standardization organizations such as IEEE, ETSI, IERC, IETF, ITU-T, OASIS, OGC, W3C, and GS1 are critical for the technology development of CPS. The international organization, IEC, ISO and DIN have established many relevant standards for CPS. This study focuses on CPS standards which considers industry technical specifications officially issued by the international standards holders such as IEC and ISO [12].

1) International Electrotechnical Commission (IEC)

The IEC, established in 1906, is the oldest international organization for Electrotechnical Standardization. The IEC is responsible for standardization in the field of electrical engineering and electronic engineering. IEC's Standardization Management Board (SMB) is the agency managing the IEC technical specifications and standardization. IEC/SMB/SG8 is the strategic working group for smart manufacturing technologies and is responsible for developing Industry 4.0 technical standards [12-13].

2) International Organization for Standardization (ISO)

The ISO, established in 1947, is an independent and non-government organization with 165 global members representing different countries. The organization brings experts together to share knowledge and develop international standards. The ISO works closely with the IEC on the development of Internet 4.0 standards. For instance, ISO/TC 184 is important to the international standardization of Internet 4.0 and focuses on automation systems and integration [14].

3) Deutsches Institut fur Normung (DIN)

DIN is a German national standardization organization founded in 1975, and is located in Berlin. DIN is a very important national standardization organization. Many of DIN's standards become ISO standards that are internationally recognized [12].

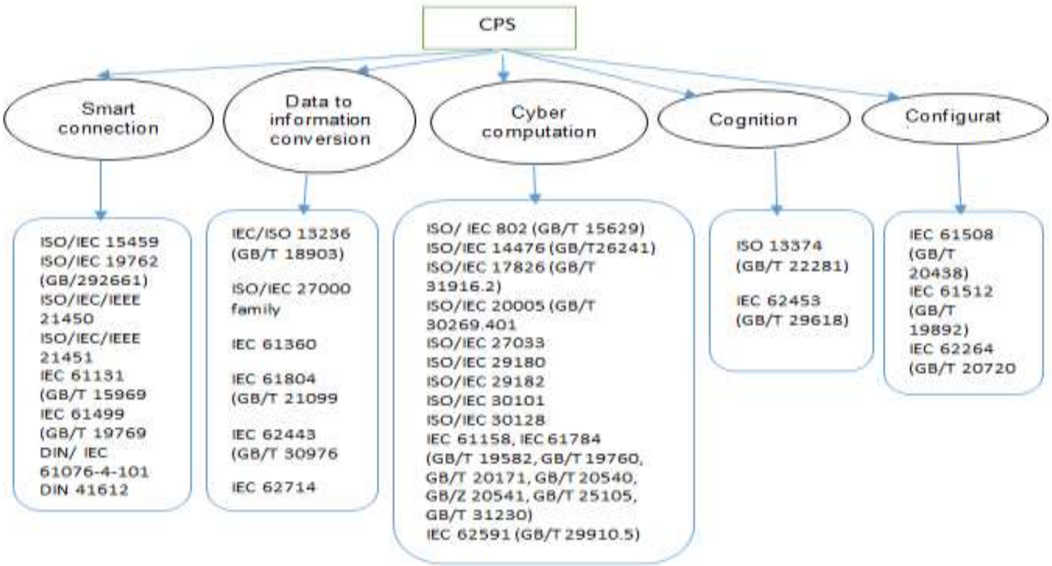
IV. PROPOSED CPS 5C FRAMEWORK FOR MANUFACTURING BASED ON STANDARD

In this section, we map the CPS ISO/IEC standards landscape to the five-layered architecture. Fig. 2 depicts the ISO/IEC standards, DIN and corresponding Chinese standards (GB) [12].

A. Smart Connection Level

The smart connection level studies how to obtain data from the physical objects. The most common technique is the use of Automatic Identification and Data Capture (AIDC). The following descriptions are the relevant standards for AIDC. The ISO/IEC 19762:2016 provides terms and definitions for AIDC. The ISO/IEC 15459 series specifies the unique identification for registration procedures, common rules, individual transport units, individual products and product packages, individual returnable transport items, and groupings. Important to CPS is the use of sensors for the automatic collection of data from manufacturing systems. The ISO/IEC/IEEE 21450:2010 defines the basic functions required to control and manage smart sensors. The ISO/IEC/IEEE 21451 series defines the Network Capable Application Processor (NCAP) information model, communication protocols, and Transducer Electronic Data Sheet (TEDS) formats for smart sensors. The standard methods to control these sensors are very important. The IEC 61131 series identify the principal functional characteristics of programmable controller systems. The IEC 61499 defines a generic model for distributed control systems based on the IEC 61131 standard.

Fig. 2. CPS 5C Framework for Manufacturing Based on Standard



The IEC 61131 and IEC 61499 help establish a reliable, interchangeable control system.

B. Data-to-Information Conversion Level

Data-to-information conversion defines processing data from the smart connection level and analyzing the information. The IEC 61804-3, IEC 61804-4, IEC 61804-5, and IEC 61804-6 (Electronic Device Description Language, EDDL) are used to describe the characteristics of devices. The IEC 61360 series provides a basis for the clear and unambiguous definition of characteristic properties, i.e. data element types, of all elements of electro technical systems from basic components to sub-assemblies and full systems. Further, the IEC 62714 series provides a data exchange format called the Automation Markup Language (AML). The above standards ensure that there is a unified data format. The IEC/ISO 13236:1998 establishes a high-quality system for the Information Technology (IT) environment. Since the security of data is an important issue, the ISO 27000 standard provides the best practice recommendations for information and security risks management and control. The IEC 62443 series (ISA99) is used to ensure the security of industrial automation and control systems and provides comprehensive security protection.

C. Cyber Computation Level

Communication is the most important element considered at the cyber and computation control level. The CPS data and information exchange require several relevant standards which include wired and wireless communication. The ISO/IEC 8802 provides the set of international standards which describe local area networks. There are several standards for wired communications: the IEC 61158 series and IEC 61784 series are standards for fieldbus types and profiles including foundation field buses, common industrial protocols, PROFIBUS and PROFINET, P-Net, World FIP, INTERBUS, Swift Net, CC-Link, HART, VNET/IP, TC net, Ether CAT, Ethernet POWERLINK, Ethernet for Plant Automation (EPA), Modbus, SERCOS, Rapi Net, Safety Net p and MECHATROLINK. These protocols enable real-time distributed control in CPS and wireless communications. The IEC 62591:2016 (Wireless HART™) and IEC 62601:2015 (WIA-PA) are suitable for industrial wireless communication of industrial measurement, monitoring, and control. The ISO/IEC 14476 series enhances the communications transport protocol to ensure that there is a good Quality of Service (QoS). A good industrial network requires the above communication standards to link the sensor network and machine network. ISO/IEC 20005:2013, ISO/IEC 29180, ISO/IEC 29182, ISO/IEC 30101:2014, and ISO/IEC 30128:2014 are used to build intelligent, reliability and secure sensor networks. There are several standards related to the cyber level. The ISO/IEC 17826:2012 specifies the interface to access cloud storage and to manage the data stored within. The ISO/IEC 27033 series ensures network security. The IEC 62769 series (FDI) is used to integrate the devices with the use of communications technology.

D. *Cognition Level*

The cognition level focuses on monitoring and making decisions. The ISO 13374 series provides the basic requirements for open software specifications, which allow machines to monitor data and information processing and communication. The IEC 62453 helps integrate all devices regardless of the suppliers.

E. *Configuration Level*

The configuration level contains the standards of overall control for CPS. The IEC 61512 defines the models for batch control used in the process, the terms and the data models. The IEC 62264 used for enterprise control system integration increases uniformity and consistency of interface construction. The standard reduces the risk, cost, and errors associated with implementing these interfaces. The IEC 61508 increases security and ensures life cycle safety for industrial process control.

TABLE II. DISCUSSION ON THE STANDARDS FOR EACH LAYER OF THE CPS 5C FRAMEWORK

5 Components Layers	Scope of Deliverable
The first layer is for smart connection that obtains external information and data through sensors. The sub-technical fields consist of embedded systems, 3D printing, robotic sensors, power, energy, cameras, actuators, controllers, circuits, plug and play, enterprise manufacturing systems, and condition-based monitoring.	ISO/IEC 15459: Information technology - Automatic identification and data capture techniques - Unique identification, ISO/IEC 19762:2016: Information technology - Automatic identification and data capture (AIDC) techniques - Harmonized vocabulary. ISO/IEC/IEEE 21450:2010: Information technology - Smart transducer interface for sensors and actuators - Common functions, communication protocols, and Transducer Electronic Data Sheet (TEDS) formats, ISO/IEC/IEEE 21451 series, Information technology - Smart transducer interface for sensors and actuators. IEC 61131 series, Programmable controllers, IEC 61499 series, Function blocks, GB/T 29261 series, Information technology - Automatic identification and data capture (AIDC) techniques – Vocabulary, GB/T 15969 series, Programmable controllers. GB/T 19769 series, Function Blocks for industrial - process measurement and control system.
The second layer manages data-to-information conversion. The sub-technical fields of the second layer consist of data processing and smart analysis. Data processing includes image and video processing systems, data security, database management systems, multidimensional data correlation, and data harmonization. Smart analysis includes self-awareness, prediction, statistical evaluation, power management techniques, diagnostics and health management.	IEC/ ISO 13236:1998, Information technology - Quality of service: Framework. ISO/IEC 27000 family, information technology - security techniques. IEC 61360 series, Standard data elements types with associated classification scheme for electric items. IEC 61804-3, IEC 61804-4, IEC 61804-5, IEC 61804-6 Function blocks (FB) for process control - Electronic device description language (EDDL. IEC 62443 series (ISA99), Security for Industrial Automation and Control Systems. IEC 62714 series, Engineering data exchange format for use in industrial automation systems engineering - Automation markup language.
The third cyber computation layer is referred to by the short name, cyber. The goal of the cyber layer is to collect information for a broad range and create a comprehensive communication platform for components and systems. The sub-technical field consists of communication, middleware, software, a central information hub, computation, and networked control	ISO/IEC 8802 series, Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks. ISO/IEC 14476 series, Information technology - Enhanced communications transport protocol. ISO/IEC 17826:2012, Information technology - Cloud Data Management Interface (CDMI). ISO/IEC 20005:2013, Information technology- Sensor networks- Services and interfaces supporting collaborative information processing in intelligent sensor networks. ISO/IEC 27033 series, Information technology - Security techniques - Network security. ISO/IEC 29180 : 2012, Information technology - Telecommunications and information exchange between systems Security framework for ubiquitous sensor networks. ISO/IEC 29182 series, Sensor networks: Sensor Network Reference Architecture (SNRA). ISO/IEC 30101:2014, Information technology - Sensor networks: Sensor network and its interfaces for smart grid system, ISO/IEC 30128:2014, Information technology - Sensor networks - Generic Sensor Network Application Interface, IEC 61158 series, Industrial communication networks - Fieldbus specifications, IEC 61784 series, Industrial communication networks – Profiles. IEC 62591:2016, Industrial networks – Wireless communication network and communication profiles - Wireless HART™, IEC 62601:2015, Industrial networks - Wireless communication network and communication profiles - WIA-PA, IEC 62769 series, Field Device Integration (FDI).
The fourth level is the cognition layer. The data from the cyber level is cognitive based and used for decision-making. The sub-technical fields consist of information display, monitoring systems, and decision-making.	ISO 13374 series, Condition monitoring and diagnostics of machines - Data processing, communication and presentation. IEC 62453 - Field device tool (FDT) interface specification.
The last layer is the configuration layer. The goal of configuration is to achieve self-adjustment in response to external parameters, demand, and environmental changes. The sub-technical fields consist of controls and adjustment.	IEC 61508 series, Functional safety of electrical/ electronic/ programmable electronic safety-related systems. IEC 61512 series, Batch control. IEC 62264 series, Enterprise - control system integration.

F. *Discussion*

Fig. 2 illustrates that all the different layers have been at that time tackled by standardization, but independently since no standard exist at the interface in between different layers, and no standards are tackling two levels at the same time. Fig. 2 links the CPS five components layer with the specific standard organizations. To go a step further, Table 2 details the sub-technical fields of the 5 components layers with the corresponding ISO, IEC, and GB/T standards.

V. CONCLUSION

Cyber Physical Systems are expected to play a major role in the design and development of future engineering systems. They are one of the key technologies of Industry 4.0. Nevertheless, there are still important challenges ahead that need to be tackled for CPSs to develop their full potential. A challenge of prime importance is the standardization aspect. This paper provides a literature review of CPS components for smart manufacturing, CPS challenges for smart manufacturing. It focuses on CPS standardization challenges, roles and functions of standard, standardization organizations, and provide a comparison of standard CPS 5C framework for manufacturing. This review and the proposed framework intend to help industry to understand the aforementioned aspects of CPS. This research must also benefit small and medium companies to integrate Industry 4.0 based on standards.

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